# The State of High Energy Physics

Edited by
Melvin Month, Per F. Dahl,
and Margaret Dienes

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**(BNL/SUNY Summer School, 1983)**

**Edited by**
**Melvin Month, Per F. Dahl, and Margaret Dienes**

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# The State of High Energy Physics

(BNL/SUNY Summer School, 1983)

# 1983 Summer School on High Energy Particle Accelerators

The US Summer School on High Energy Particle Accelerators is dedicated to the future of High Energy Physics.

Brookhaven National Laboratory and
State University of New York at Stony Brook
July 6-16, 1983

# PREFACE

The material contained in this volume covers lectures presented at the Symposium on the State of High Energy Physics, which was part of the third annual U.S. Summer School on High Energy Particle Accelerators, held at Brookhaven National Laboratory (BNL) and the State University of New York at Stony Brook (SUNY), July 6-16, 1983. The school, sponsored by the Department of Energy (DOE) and the National Science Foundation (NSF), is one of a continuing series of such schools organized at different high energy physics laboratories across the country. Past and planned schools are:

| | |
|---|---|
| Fermilab | July 13-24, 1981 |
| SLAC | August 2-13, 1982 |
| BNL/SUNY | July 6-16, 1983 |
| Fermilab | August 13-24, 1984 |
| SLAC | July 15-26, 1985 |

Although the school symposium was held in July, 1983, much of the material has been updated. Thus, this review substantially represents a picture of high energy physics as it currently exists with a flavor of the 1983 viewpoint.

This third summer school was planned by an organizing committee consisting of M. Month (BNL, Chairman), J.D. Bjorken (Fermilab), H. Grunder (DOE/LBL), V.W. Hughes (Yale), F.R. Huson (Fermilab), B. McDaniel (Cornell), C. Pellegrini (BNL), B. Richter (SLAC), R. Schwitters (Harvard/Fermilab), and R.R. Wilson (Columbia). P.J. Reardon (BNL) served as the local school director, and, with P. Dahl as his deputy, had the responsibility for administering the school. N.P. Samios, BNL Director, hosted the school and significantly contributed to its success.

The purpose of these schools derives from a recommendation made by a subpanel of the High Energy Physics Advisory Panel (HEPAP) that convened in 1979-1980 in order to assess the current state of accelerator R&D. The subpanel issued a strong appeal to the high energy physics community to attempt to encourage a greater number of scientists and students to work in the field of high energy particle accelerators. These national summer schools constitute one response to that appeal. Indeed, it is the main purpose of the school to attract scientists and students and to enhance their education in accelerator physics.

To carry out its mission, the school is guided in its operation by the following objectives: (i) to present in a thorough and up-to-date manner the entire spectrum of knowledge pertaining to particle accelerators; (ii) to help in the training of scientists who plan to work in accelerator physics, thereby building a base of particle accelerator specialists in this country; (iii) to encourage development of accelerator physics programs in American universities by providing text materials and training for the potential faculty of such programs; and (iv) to foster a more extensive dialogue between accelerator physicists and scientists and engineers working in particle physics and other accelerator-based sciences. Success in achieving these goals could be an important factor in continuing the advances in accelerator development necessary for a vigorous program in high energy physics and other sciences.

Each year the school produces a volume of its proceedings structured so that it can be read as a comprehensive textbook on accelerator physics and technology. The text for the 1983 BNL/SUNY school appears as Volume 127 of the American Institute of Physics Conference Series.

The field of accelerator physics and technology finds a place within the larger scientific enterprise of high energy physics. This high energy physics endeavor is an exciting adventure, probing the ultimate mysteries of physical nature; and to attempt to put this into perspective, the school offers an annual Symposium on the State of High Energy Physics, of which this volume represents the proceedings. The Symposium in general consists of a series of seminars on a broad range of subjects such as developments in particle theory and experiments, detector development, the nature and operation of high energy physics laboratories, and the status of ongoing and planned future projects. This provides a picture of the broad cultural framework of high energy physics within which the field of particle accelerators coexists. The general theme for the 1983 BNL/SUNY Symposium is related to the very large colliders envisioned by the scientific community and prompted by the current predictions of exciting new physics in the few-TeV energy region. The Symposium included a Round Table on an Ultrahigh Energy Collider, chaired by G.-A. Voss, with the following agenda:

| | |
|---|---|
| Particle Physics of Multi-TeV Collisions | J.D. Bjorken, Fermilab |
| Accelerator Technology for a Multi-TeV Collider | M. Tigner, Cornell |
| Experiments at Multi-TeV Energies | C. Rubbia, CERN/Harvard |
| Prospects of an Ultrahigh Energy Collider: A View from Washington | N.D. Pewitt, Office of Sci. & Tech. Policy |
| Planning for a Super Collider | P.J. Reardon, BNL |

These proceedings of the Symposium are the second in a series entitled The State of High Energy Physics, the first being AIP Conference Proceedings 92 (Fermilab, 1981).

Participation in the school, in terms of both lecturers and students, continues to be excellent. As anticipated, the major U.S. high energy physics laboratories (SLAC, Fermilab, and BNL) provide about 50% of the students. There have been efforts to improve university and foreign participation, primarily by greater interaction between the school, on the one hand, and U.S. universities and foreign institutions, on the other. Among other features, the following participation table shows the success that has been achieved in raising the university and foreign participation, and indeed it shows a striking increase in attendance in 1984.

Participation in Summer Schools

| Source of Students | 1981 Fermilab | 1982 SLAC | 1983 BNL/SUNY | 1984 Fermilab |
|---|---|---|---|---|
| Major HEP labs, U.S. | 65 | 92 | 78 | 94 |
| Universities, U.S. | 32 | 14 | 37 | 55 |
| Other, U.S. | 13 | 24 | 17 | 15 |
| Foreign | 10 | 19 | 16 | 31 |
| Total students | 120 | 149 | 148 | 195 |
| Total lecturers | 24 | 19 | 33 | 50 |

The school functions through an organizing committee, a school office, and a local school administration. The organizing committee meets once or twice per year as needed, determines overall school policy, and determines the school program and lecturers. The local school administration is established each year at the institution where the school is to take place. It coordinates and operates the school and implements all school functions. The general administrative functions of the school are carried out by a central school office located at Fermilab. This office coordinates the activities of the organizing committee, maintains a school file, and is responsible for collecting and reviewing the manuscripts and organizing the publication of the school text. The office also initiates and supports various activities which advance education and documentation in the field of particle accelerators, such as the 1985 U.S./CERN Topical Course on Nonlinear Dynamics, held in Sardinia, Italy, January 31 to February 5, 1985.

The past decade has proved to be one of the most fertile in the history of high energy physics, with the many great experimental discoveries of this period having been made possible largely by the new generation of high energy accelerators. These new machines have greatly increased the maximum energy range of particle beams, and have thus opened a window to exciting regimes of higher particle interaction energies. This has culminated in the proton-antiproton ($p\bar{p}$) collider, completed more than two years ago at CERN, which has achieved an interaction energy of 540 GeV, almost an order of magnitude more than in previous experiments. But still higher energies wait to be explored. In western Europe, the CERN $Sp\bar{p}S$ Collider (the $p\bar{p}$ collider at the large CERN synchrotron, the SPS) is being upgraded in both energy and luminosity, the CERN LEP Project is in construction (LEP: $e^+e^-$ collisions at more than 200 GeV center-of-mass energy), and the DESY HERA Project has been initiated (HERA: ep collisions at about 30 GeV x 800 GeV beam energies). Meanwhile, in the United States, two new colliders in the process of development stand ready to take up the task. One is the hadron collider with colliding proton and antiproton beams being constructed at Fermilab (Tevatron I: $p\bar{p}$ collisions at about 2 TeV in the center of mass); the other is the SLAC electron-positron collider (SLC: $e^+e^-$ collisions at about 100

GeV in the center of mass.) Beyond this, we can imagine in the U.S. a program of study evolving in the next decade that is backed by a hadron-hadron collider in the multi-TeV energy range, such as the recently proposed SSC (Superconducting Super Collider) capable of collision energies up to 20 TeV x 20 TeV, and an $e^+e^-$ collider in the energy range of many hundreds of GeV. In addition, with an existing SSC, one might imagine a tandem facility which could include very high energy ep collisions or $e^+e^-$ collisions in a circular storage ring reaching perhaps ½ TeV in center-of-mass energy.

In recent years, theoretical understanding of high energy physics has exceeded the capability of experimental physics to verify many of the predictions of these theories. But this situation has been suddenly turned around with unexpected rapidity. Almost unseen, the age of the high energy hadron colliders is suddenly upon us, signalled by the great experimental achievements of the CERN Sp$\bar{p}$S Collider. In the past two years the CERN p$\bar{p}$ collider has led to the discovery of the vector bosons ($W^{\pm}$, $Z_o$) and the top quark and has produced hints of new phenomena. As experimentation with the new colliders opens up unexplored energy regimes, theory must readjust continuously in order to conform to the rapidly unfolding physical reality emerging. This is true for the operating colliders and will undoubtedly continue to be so for the ones just on the horizon.

The process of accelerator energy increase followed by new elementary particle discoveries has been going on since the 1930s, with accelerator energies increasing at the rate of about an order of magnitude every seven years. In the past, technological innovation leading to new accelerators has been at the heart of this process, with the strong-focusing synchrotrons of today capable of achieving energies six orders of magnitude higher than those achieved by the cyclotrons of forty years ago. If our quest into the nature of matter is to continue into the future, we need abundant ideas to further the advances in technology. But to make this happen, the need above all is for new ideas, which is a challenge that can be met only by new and younger people entering the accelerator field. It is our hope that the summer school will stimulate participants to think about and enter this bold venture to conceive and build new accelerators so as to push back the frontiers of energy. By so doing, they will join a new generation of high energy physicists dedicated to the study of new mass regions heretofore impenetrable.

Melvin Month
Chairman, Organizing Committee
U.S. Summer School on
High Energy Particle Accelerators
October 1984

## ACKNOWLEDGMENTS

The 1983 Summer School on High-Energy Particle Accelerators owed much of its success to the dedicated and enthusiastic behind-the-scene contributions of a large number of individuals and supporting groups at Brookhaven National Laboratory and the State University of New York at Stony Brook. Thus, in addition to the members of the school organizing committee, the speakers whose lectures appear in this volume, the symposium speakers whose seminars will appear in a forthcoming companion volume, and members of both the local school administration and the editorial committee, we wish to acknowledge especially the following: D. Barton, R. Blumberg and C. Woody for their efforts as scientific secretaries for the lecture program; A. Forkin and A. Brody for coordinating school activities between BNL and SUNY; M. Heimerle for her continuing expert help in the transaction of school business; A. McClain for coordinating school attendees and handling manuscripts; G. Walczyk for coordinating audiovisual instrumentation; H. Boyd and P. Glenn and the excellent BNL Staff Services Division for arranging physical facilities and numerous supporting services; and N. Gargliardo and her staff in the BNL Travel Office for their patient and expert assistance with travel arrangements to and from the school. We must also acknowledge the invaluable expertise of various groups within the BNL Photography and Graphic Arts Division in manuscript preparation and processing under the general coordination of K.E. Boehm: Word Processing under M. Wigger, Quick Copy Services under J.P. Hanson, Illustration under E.J. Caiazza, Photography under B.S. Style, and Composition under L.J. Casey.

Finally, we thank Professor J.H. Marburger, President of SUNY, for his warm welcoming remarks during the opening session, and N.P. Samios, BNL Director, who closed the school with a most interesting discussion of the history of accelerators both at BNL and in high-energy physics.

P.J. Reardon
M. Month

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*The basis for this paper was a lecture given by W.A. Wallenmeyer (Director of the Division of High High Energy Physics of the Department of Energy) at the 1983 Summer School at BNL. The author of this paper would like to express his appreciation to Dr. Wallenmeyer for his encouragement and support and to the program office staff at DOE for their cooperation and help. The actual material was accumulated from the DOE congressional budget writeup and briefings, from descriptive information prepared by the national laboratories, from various surveys and reports commissioned by the DOE and its scientific advisory body HEPAP, and from other documents.

# HIGH ENERGY PHYSICS IN THE UNITED STATES

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## I. INTRODUCTION

### A. Overview of the Field

High energy physics is the field of basic research which addresses the most fundamental questions concerning the nature of the physical universe, i.e., the basic nature of matter, energy, space, and time. Its objective is to find the fundamental constituents of matter (the elementary particles) and the forces that act between them. Recent developments in experimental and theoretical physics point the way to an increasing understanding of the basic structure of matter and to an overall synthesis encompassing all the forces observed in nature.

Exploration of the ultimate constituents of matter requires two essential tools: particle beams of high enough energy and intensity to probe the structure within the nucleons, and detectors sensitive and complex enough to detect and decipher that structure.

The particle beams are generated by complex and large accelerators of various types, including linear accelerators, circular accelerators (synchrotrons), and colliding beam machines. The more fundamental the structure to be probed, the higher are the energies needed; therefore, attempts to probe deeper into the structure of matter require new accelerator capabilities and often new accelerator technologies. In recent years, devlepments in superconducting accelerator magnets and in colliding beam technology have provided the base for the next step in major facility development and construction.

Accelerating particles and bringing them into collision with targets and other beams is only half the task. The other half is to observe and distinguish the particles that emerge from these collisions with particle detectors. Much ingenuity has gone into the conception, development, and fabrication of these devices that can simultaneously register the passage of many subatomic particles traveling at essentially the speed of light, recognize their nature, and measure their energy and other properties.

Particle detectors have come to have a highly sophisticated set of capabilities due to the rapid development of electronics and other technology developments in recent years. Conversely, R and D to meet detector requirements has contributed to developments in a variety of technologies. This process, in response to the increasingly stringent requirements of experimentation at higher energies, has resulted in great improvements in precision and sensitivity and given rise to the modern detector, a large, complex multicomponent instrument. The increased detector capability coupled with the higher energy and intensity of accelerator beams has resulted in massive amounts of data for analysis, which is done with powerful computers. Some computers are integrated into the detectors and are used to control the apparatus and to analyze data in real time in order to provide rapid feedback of results to guide the conduct of the experiment. Theoretical physicists and accelerator physicists have also come to rely on computers for the complex calculations needed to solve forefront theoretical problems and to simulate the properties of accelerators under design.

B. Planning for the U.S. High Energy Physics Program

High energy physics research is dependent on large complex particle accelerators, colliding beams, and detector facilities, and requires long lead times for planning and implementing intricate experiments and for designing and constructing advanced facilities. Typically, the time from the original concept for an experiment to the publication of results is 3 to 6 years and the time from conceptual design to operation for a major facility is 5 to 10 years or more. In an endeavor with such long lead times effective long-range planning is essential. High energy physics has a long record of efficient long-range planning. Since 1967 planning for the U.S. High Energy Physics Program has benefited substantially from advice from the High Energy Physics Advisory Panel (HEPAP) and its subpanels. Figure 1 indicates the role of the Department of Energy (DOE) as the lead agency responsible for this Program.

Institutionally, the program structure has at its core the large national accelerator laboratories (BNL, Fermilab, and SLAC managed by DOE and Cornell by NSF). Experimental support for the High Energy Physics Program is provided by 120 groups from 64 universities and laboratories with DOE funding and by 90 groups from 52 institutions with NSF funding; theoretical expertise derives form 57 DOE funded

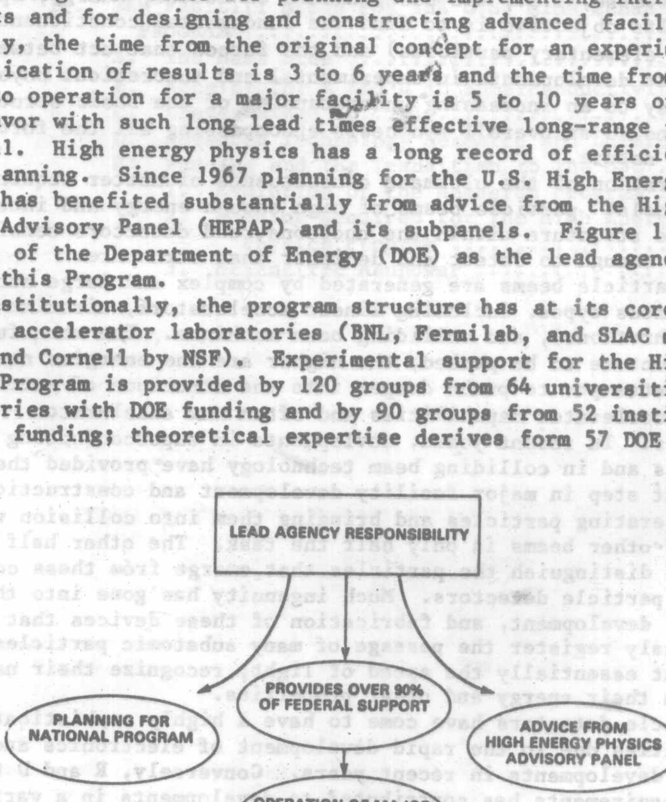


Figure 1. The role of the Department of Energy as the lead agency responsible for the U.S. High Energy Physics Program. The other U.S. government agency responsible for support to High Energy Physics is the National Science Foundation (NSF).

universities and laboratories and 47 NSF funded institutions. The DOE management of the program is governed by a program philosophy which can be summarized as follows:

- Ideas and proposals are generated by scientists in the field.
- The agency, with input from the field, establishes policy, plans, and budgets.
- The agency provides funding allocations and general guidance to the field.
- The laboratory management or university principal investigator is entrusted with the responsibility for the day-to-day detailed management of the program.
- The agency reviews and monitors progress and takes corrective action where appropriate.

The annual budget process by which funds get allocated is a rather elaborate one, beginning with proposals from the field and culminating in a funding decision process involving the Congress, the Office of Managment and Budget (OMB), and the Department of Energy (DOE).

Within the DOE, the Division of High Energy Physics (DHEP) first puts together a proposed High Energy Physics budget. This budget then moves to the Office of High Energy and Nuclear Physics (OHENP) where it gets folded in with the Nuclear Physics Budget. As the budget proceeds up the organizational ladder, there is negotiation and budget fitting and reworking. After OHENP, the Office of Energy Research (OER) has a budget which includes Fusion and Basic Energy Sciences. Finally, the budget goes through the Undersecretary of Energy and the Comptroller and becomes a total DOE Budget including other parts of the Department's concerns such as Nuclear Energy and Nuclear Weapons. The OMB acts for the President and pulls together from all the agencies the President's Budget, which is then sent to the Congress. The House and the Senate each act on the President's Budget through three committees: the Budget Committee, the Authorization Committee, and the Appropriation Committee. Hearings are held before subcommittees of each of these in both the House and Senate. Coming out of the hearings, House and Senate bills provide budget figures. If they differ there is a House and Senate conference, and from this conference comes a joint House and Senate bill. The bill returns to the President and with his signature it becomes law. The bill then returns down the line essentially the same way it went up, and apportionment is made at each level.

The government operates on a fiscal year basis. The fiscal year begins on October 1. The budget process begins with the receipt of requests from the field about 18 months before the beginning of the fiscal year. The DOE then sends its request to the OMB about 13 months before the fiscal year begins. Sometime in January, the President's Budget is released and sent to Congress about 9 months before the fiscal year starts. Under ideal circumstances, Congress will return the budget bill to the President about 3 months before October 1; sometimes this doesn't happen, and no budget bill is passed into law by the beginning of the fiscal year. Since government operations must continue, the government then proceeds on the basis of a continuing